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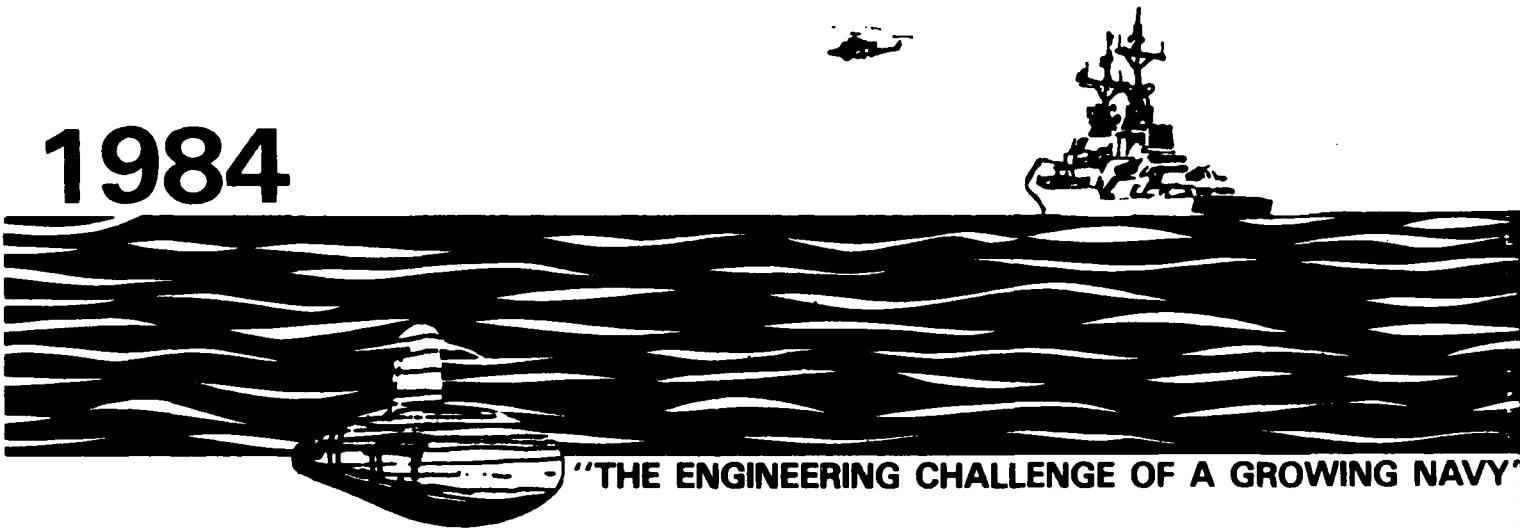
"THE ENGINEERING CHALLENGE OF A GROWING NAVY"

SHIPBOARD CORROSION ENGINEERING

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ABSTRACT

The Navy has increased its emphasis on the prevention and control of shipboard corrosion as a means of reducing the life-cycle costs of ships. This emphasis is required due to the increased technical sophistication of modern warships, and the reduction in the numbers of sailors available to perform "chip-and-paint" maintenance. Designing and building ships to prevent corrosion problems, and the use of modern corrosion control techniques has been demonstrated to be an effective method for reducing ship-force maintenance man-hours, thereby supporting the low-manning concept inherent in the disign of many warships. The use of improved coatings including epoxy paints, metal spray coatings, water-borne coatings, ceramic-metal coatings for fasteners, and powder coatings technologies has been shown to reduce ship maintenance costs and to improve the performance of shipboard equipment.

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INTRODUCTION

Controlling rust on ships is not just a nice thing to do, it is an essential element of good ship design. Corrosion of ships and ship-borne equipment affects manning levels, equipment availability, and overall readiness. Proper use of good shipboard corrosion engineering allows well designed ships and equipment to perform at their best. Conversely, poor corrosion engineering can defeat the best "theoretical" design.

Corrosion engineering of ships and ship-borne equipment has received increased, high level Navy attention due to the need to improve the Navy's retention and utilization of personnel. Shipboard corrosion engineering has been demonstrated to be an important method for reducing maintenance and, thereby, meeting this requirement. The basic facts that make the concern about maintenance requirements an important and permanent factor for all ship design disciplines are examined. The principles of corrosion science and their application to shipboard corrosion engineering. We conclude with a discussion of the corrosion control techniques that are being used on naval ships and the direction of current Navy corrosion control programs.

MANPOWER AVAILABILITY

Improving the effective use of manpower is critical to the Navy of the 1990's. Any design philosophy that does not recognize this fact does a serious disservice to the Navy and can be expected to cause serious problems in the future. Four facts make this inescapable:

(1) The available manpower pool of military age Americans will be 25% less in the mid 1990's than it was in 1980. The Navy will need to recruit a larger share of the military age labor force just to stay even with its low 1980 manning level.

(2) The increase of fleet size to a six-hundred ship Navy will put increased demands on Navy manpower needs and utilization.

(3) The technical sophistication of modern warships requires sailors with increased technical skills. The days when large deck gangs were available for rust-busting and painting are gone. The majority of a technical sailor's time should be directed at increasing his technical proficiency, not doing general maintenance.

(4) The increased use of automatic equipment has reduced both the size of the ship crews and the number of non-technical personnel available for routine corrosion control.

Because of these manpower related problems, the major goals of the Navy's shipboard corrosion control program is (a) the implementation of techniques to reduce the number of maintenance manhours required to prevent corrosion, (b) to repair equipment damaged by corrosion, and (c) reduce the life cycle costs of ship ownership.

MANPOWER PRODUCTIVITY

Shipboard corrosion engineering is aimed at increasing manpower productivity by:

(a) reducing non-productive fleet working hours,
(b) improving equipment reliability and maintainability.

The term "non-productive" working hours, does not mean that a sailor is not working productively. During non-productive working hours a sailor may be very productive at the job he has been assigned--but the job he is doing is not what he is supposed to be doing! An example of such work occurs when a computer technician has to spend time chipping and painting. The Navy may be getting an excellent paint job, but the job the sailor was recruited for is not being done.

The reliability and maintainability of shipborne equipment, in particular weather exposed equipment, is seriously influenced by corrosion. Corrosion reduces reliability by corroding electrical connectors and mechanical causing equipment to fail. Corrosion makes routine maintenance more difficult (e.s., by freezing a jointand making it hard to disassemble equipment), or by causing structural damage to equipment. All to often, the correction of corrosion related problems will take more time than the originally planned maintenance action.

In one case we know of, it took 24 man-hours to perform a 2 man-hour motor replacement because three fasteners had corroded. Because of this corrosion it took 23 man-hours to remove the access plate to get at the motor, while it took only one man-hour to perform the motor replacement.

PRINCIPLES OF CORROSION

The National Association of Corrosion Engineers defines corrosion as:

> The deterioration of a substance (usually a metal) or its properties because of a reaction with its environment.

By definition, corrosion engineering is a very broad subject that encompasses non-metallic as well as metallic substances. Shipboard corrosion engineering is primarily concerned with metallic corrosion (rusting) caused by contact with seawater, the most visble form of corrosion on ships, and our discussion will be limited to this type of corrosion. This discussion covers the common metals involved in shipboard corrosion and is based on the general principles of corrosion science (1,2,3).


CORROSION ELECTROCHEMISTRY

Corrosion engineering in the marine environment is primarily concerned with reactions where the electrolyte is either seawater or freshwater, and where the reactions occur at temperatures ranging from zero to one-hundred degrees Celsius. This discussion will be limited to these conditions: The basic conditions needed for corrosion to occur are illustrated in Figure 1. These requirements are:

 a. a material which corrodes (an anode),
 b. a material which corrodes slowly, if at all (a cathode),
 c. an electronic path between these materials,
 d. an electrolyte to transport ionic material to and from reaction sites on the materials.

A corrosion cell is formed when all the above requirements are met. When two metals are combined into cell, one of the metals will corrode while the other metal will corrode very slowly, if at all. The metal which corrodes is called the anode while the metal which does not corrode (or corrodes very slowly) is called the cathode.

The general chemical equation for the corrosion of a metal is written in the form:

$$M \longrightarrow M^{(n+)} + ne^- \qquad E = ? \text{ volts}$$

where M stands for any metal and M(n+) is the metal ion that goes into solution, and n is the number of electrons (e-) released by the reaction. This is called a half-cell reaction since it describes the reaction occuring in one-half of the corrosion cell. Each half-cell reaction has a characteristic voltage when compared with a standard reference cell. The values given in this discussion are based on the Standard Hydrogen Electrode reference cell.

The more negative the voltage, the more reactive the metal. Metallic sodium, which reacts violently with water, has a half-cell voltage of -2.7 volts. Gold, which is inert in water, has a half-cell voltage of +1.42 volts. When corrosion occurs a metal loses mass due to the formation of metal ions. This reaction is called the Anodic Corrosion Reaction. When two metals are combined the one with the more negative half-cell voltage will corrode. The algebraic difference between the anodic half-cell potential and the cathodic half-cell potential determines the net voltage for the corrosion cell. The more negative this value, the greater the tendency for corrosion to occur.

The corrosion (anodic) reactions for metals commonly used on ships are given by the following equations:

$$Copper \quad Cu \longrightarrow Cu^{2+} + 2e^- \quad E = 0.34v$$

$$Iron \quad Fe \longrightarrow Fe^{2+} + 2e^- \quad E = -0.44v$$

$$Zinc \quad Zn \longrightarrow Zn^{2+} + 2e^- \quad E = -0.76v$$

$$Aluminum \quad Al \longrightarrow Al^{3+} + 3e^- \quad E = -1.66v$$

$$Magnesium \quad Mg \longrightarrow Mg^{2+} + 2e^- \quad E = -2.38v$$
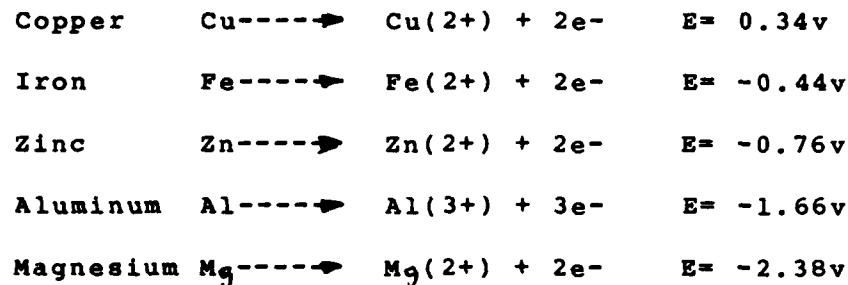
The above equations are only one-half of the chemical equation for corrosion. A second reaction, or set of reactions, occurs at the other materials forming the corrosion cell. These reactions (called cathodic corrosion reactions) are:

$$Oxygen\ Reduction \quad O_2 + 2H_2O + 4e^- \longrightarrow 4OH^- \quad E = +.40v$$

$$Metal\ Ion\ Reduction \quad M^{3+} + e^- \longrightarrow M^{2+}$$

$$Metal\ Deposition \quad M^{2+} + 2e^- \longrightarrow M$$
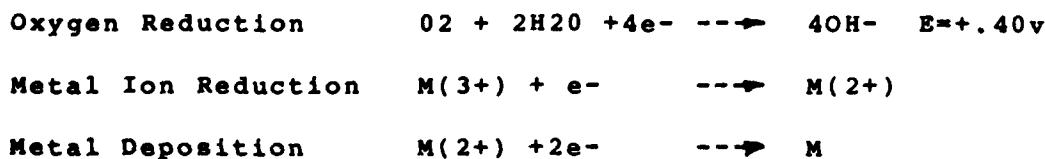
COMMON CORROSION CELLS

In this discussion we will use the term steel and iron (Fe) interchangeably to mean mild steel. This does not mean that electrochemical properties can be completely described from the

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properties of the individual elements alone. Alloy composition and processing variables must be known to avoid corrosion problems. However, the majority of shipboard corrosion problems can be understood in terms of the following electrochemical corrosion cells.

When iron (Fe) and zinc (Zn) are connected in a cell the following reacations occur:

ANODE   Zn   --------➤ Zn (2+) + 2e-

CATHODE   Fe(2+) -------➤ Fe
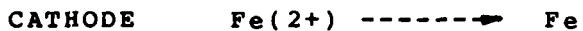
NET CELL VOLTAGE = -0.32

In this case the zinc corrodes and the iron is prevented from corroding. This reaction is the basis of the protection given by zinc anodes and zinc containing coatings.

Another corrosion reaction of importance in ship design is that between copper and iron:

ANODE   Fe   ------➤ Fe(2+)

CATHODE   Cu(2+) -----➤ Cu
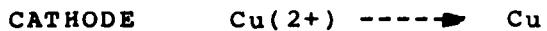
NET CELL VOLTAGE = -0.78

In this reaction the steel corrodes. This type of corrosion occurs in the underwater hull area where a bare steel area will corrode to protect the copper alloy propellor. This also causes problems if steel fasteners are used join copper alloy pipes.

When iron and aluminum are connected the reactions occur as follows:

ANODE   Al   ----------➤ Al(3+)

CATHODE   Fe(2+) --------➤ Fe
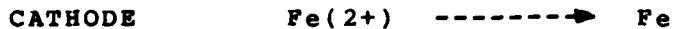
NET CELL VOLTAGE = -1.22

This reaction is the basis of both effective corrosion control procedures, and major corrosion control problems. In this reaction the aluminum corrodes while the iron does not. The use of aluminum anodes to provide cathodic protection uses this reaction to control the corrosion of steel. Unlike zinc, aluminum is also used as a structural material on ships and this reaction can lead to serious problems. If aluminum plates are connected with steel fasteners the aluminum corrodes to protect the steel fastener and serious corrosion can occur. Similarly, joining steel plates with aluminum fasteners will cause failure of the fastener since it will dissolve to protect the steel.

Connecting magnesium and steel in a seawater environment results in the following reactions:

ANODE $\quad\quad\quad\quad$ M $\quad\quad$-------▶ $\quad$ M (2+)

CATHODE $\quad\quad\quad$ Fe(2+) ---▶ $\quad$ Fe

NET CELL VOLTAGE = -1.94

In general, magnesium has similar properties to aluminum and is used as a sacrificial anode to protect steel from corroding. When used as a structural material, it is necessary to avoid situations where it will corrode by being placed in contact with steel. In general, its problems and properties are similar to those encountered with aluminum.

The driving force of corrosion is electrochemical differences, and not simply differences between elements. Electrochemical differences, and the ensuing potential for corrosion, can arise between pieces of the same type of stock and even between adjacent spots on the same piece of metal. The corrosion of steel is the most common example of this type of corrosion. The corrosion cell for steel in aerated seawater is:

ANODE $\quad\quad\quad\quad$ Fe $\quad\quad\quad\quad\quad\quad\quad\quad$-------▶ $\quad$ Fe(2+)

CATHODE $\quad\quad\quad$ O_2 + $2H_2O$ + 4e- $\quad$-------▶ $\quad$ 4 OH-
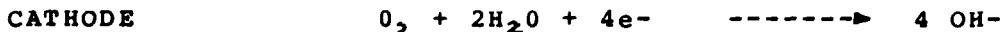
NET CELL VOLTAGE = -0.84

In this cell a dissolved gas (oxygen) is the cathode. Since oxygen is not a part of the ships structure (as copper or aluminum might be) steps that can be taken to eliminate oxygen are effective in preventing iron corrosion.

PREVENTING CORROSION

As mentioned previously, electrochemical corrosion requires the existence of the following conditions:

$\quad\quad$ a. $\quad$ an anode and a cathode
$\quad\quad$ b. $\quad$ an electronic path between these materials
$\quad\quad$ c. $\quad$ an electrolyte to transport ionic materials between reaction sites.

Control of one or more of these factors can eliminate, or drastically reduce, the damage caused by corrosion. Control of electrical differences between the anode and the cathode is largely accomplished by choice of alloys and fabrication methods. Control of electronic and electrolyte currents requires establishing mechanical and electrical barriers to their flows. This is

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accomplished by using organic and inorganic paints which act as barriers, and which can release chemical compounds which inhibit the corrosion of the underlying metal.

ELECTROCHEMICAL COMPATABILITY

The extent to which metals will corrode is determined by the voltage developed when they are immersed in an electrolyte and electrically connected to form a corrosion cell. The greater the voltage developed, the greater the tendency for the anode to corrode while the cathode corrodes little, if at all. Table 1, gives the relative corrosion tendencies of different metals in seawater. Metals which are grouped together can generally be joined in seawater without accelerating the corrosion of any of the metals involved. When metals from different groups are joined the more active metal will corrode at an accelerated rate while the less active metal will corrode slowly, if at all. The tendency to corrode will be greatest for the groups which are farthest apart.

The voltage difference only determines the potential for corrosion to occur, it does not determine the rate at which corrosion will occur. The factors which cause these differences are given in Table 2. The effect of these factors are different for each material, as is the magnitude of their influence on the rate at which metals corrode. Moreover, these effects are seldom encountered alone and combinations of effects can occur (e.g., pressure, temperature and stress occur simultaneously on many types of equipment). Oxygenation and concentration differences are particularly noticeable in flowing seawater and are often responsible for converting slow, uniform corrosion to rapid pittingand structural failure of materials. A detailed discussion of these phenomena is presented in references (1), (2) and (3).

ELECTRONIC PATH

If the path for electron flow between the anode and cathode is broken the accelerated corrosion of the anode will not occur. This approach is most commonly used when the metals used form very active corrosion cells (e.g., when aluminum must be connected to steel). Breaking the electron path requires placing an electrical insulating layer between the faying surfaces of the metals and preventing metal-to-metal contact.

ELECTROLYTE

Controlling contact with the electrolyte is accomplished by either forming a barrier between the electrolyte and the metal, or by designing the structure in such a fashion as to minimize contact with electrolyte. The design approach requires carefull consideration of means to allow electrolyte to drain from the surface or to have it physically removed. In the case of exposure to salt water it is possible to remove the strong electrolyte (sea water) by rinsing the structure with fresh water. Whenever possible, washing a salt water exposed surface with fresh water is an excellent means of reducing corrosion. This technique is used for aircraft and some seawater exposed equipment but is obviously impractical for large ships.

The most common method used to break contact with electrol.e is to use a paint that is impervious to penetration by the electrolyte, and thereby reduces or eliminates the contact be 'en the electrolyte and the metal. This barrier can also be natu .1y generated, as is the case with the oxide film that forms on t.e surface of aluminum and stainless steel alloys. In either cas. the barrier prevents the ions in the electrolyte from contacting the metal and slows or stops the corrosion reaction.

CORROSION ENGINEERING

Designing to control corriosion requires making conscious design decisions to eliminate the conditions which corrosion science has shown to increase corrosion. The most critical single concept that must be remembered is that the worst environment encountered in service determines the effectiveness of a corrosion engineering design. Nominal environments, or the average service environment are important, but extreme care has to be taken to avoid making serious errors by ignoring the worst-case environment.

For ships, or shipborne equipment, this means that there is no such thing as a dry shipboard environment. Even mominally dry areas can get wet anyway. Perhaps the most common design defect encountered on ships is the "dry" void or enclosure that is treated with a low cost corrosion control system designed for dry interior environments. Unfortunately, there is no such thing as a dry space on a ship. ALL spaces are wet, if for no other reason than the condensation of moisture when humid air meets cold steel. More commonly, the void or enclosure will leak, or water will enter due to some accident. A void designed to be dry will not have drainage or discharge lines and the water introduced will be trapped, providing the electrolyte needed for the corrosion reaction to occur. When the void is sealed a perpetual high humidity condition will exist throughout and corrosion will be rapid and extensive.

A good example of this problem occured in the "dry" voids in the sponsons of aircraft carriers. Leaking "water-tight" hatches, and water entry through open hatches, allowed water into the "dry"

void. These voids were designed to be dry and were preserved with paints designed for use in dry interior spaces. Without drain holes in stiffeners to allow water to drain to a collecting area, and without adequate provision for removing water, corrosion was rapid and severe.

DESIGN AND FABRICATION

Structural design and fabrication details can minimize corrosion by helping to prevent the accumulation of electrolyte (water). Designing deck camber for drainage is an obvious example. Design should minimize pockets areas where water can form puddles. Drainage holes in stiffeners and positioning of structural members to prevent trapping water are good techniques. Of critical importance is preventing the formation of crevices and narrow, undrainable gaps between metals. Such gaps are formed when plates are welded or bolted together, or when two assemblies are placed close together.

Proper installation of drains is required to keep them from defeating their purpose. A simple drainage hole can be a source of corrosion problems if it is not wide enough to paint, and if the edge is not beveled to reduce its sharpness. Drains in voids and tanks need to be in a position where they can drain the void completely. Drains need to be positioned where they will function with normal ship trim. Drains will clog, and consideration must be given to allowing for clearing the drain line.

Joinings of dissimilar metals (particularly aluminum and steel) requires care to avoid serious corrosion problems. The importance of eliminating gaps and seams is much more important for this situation than otherwise. In addition, the precise details of how the metals are joined has a tremendous influence on the corrosion resistance of the assembly. In addition, it is critical that electrical contact between the fastener and the metals be broken to eliminate the electrical path that is essentialfor corrosion to occur.

IDENTIFICATION OF CORROSION PRONE AREAS

Corrosion prone areas are present in all ship designs because of the practical impossibility of eliminating corrosion prone materials or undesirable structural details. There are situations where strength, weight, or boundary constraints will result in an undesirable design when viewed from a corrosion engineering perspective. As a consequence, it is essential that the designerbe aware of these situations and select corrosion control procedures

to minimize the inherent design weakness. Equally important, the designer must highlight the potential corrosion problems in the design to allow effective planning for maintenance support. This action is essential to prevent logistic surprises during the life-cycle of the ship or equipment.

CORROSION CONTROL SYSTEMS

There are two basic classes of corrosion control systems, those intended for intermittent exposure to moisture and those designed for continous immersion service. The intermittent exposure systems are typically those used on the "topside" portions of ship exteriors above the waterlineand most ship interior spaces. Continuous exposure systems are used in ballast and trim tanks, wet bliges, fuel/ballast tanks, wet spaces (scullary, shower), and on the underwater hull. The primary difference between these systems is the mechanism used to protect the metal. Continuous immersion systems use insulating layers coupled with electrochemical systems to prevent corrosion. Intermittent exposure systems rely on the formation of an insulating layer to prevent corrosion. Intermittent exposure conditions have the most impact on ship's force maintenance requirements and are the only systems covered in detail in this paper.

GENERAL CORROSION CONTROL PROCESSES

The four major processes used for shipboard corrosion control are: (a) metal spray coatings, (b) high performance organic and inorganic coatings, (c) sealants, (d) improved fastener materials. We will review these general processes before looking at specific systems.

Metal spray coatings are formed by melting a metal and spraying the molten metal onto the surface to be protected. The metal solidifies in place and forms a tightly adhering barrier to protect from corrosion. For shipboard applications the most commonly used metal is aluminum. It has been demonstrated that the aluminum must be painted to seal the surface and obtain long service life.

High performance organic and inorganic coatings consist of chemically curing (two component) epoxy paints, inorganic zinc paints, high performance single component vinyl paints. These coatings are applied using conventional application techniques (e.g., brush, roller, spray).

High performance sealants are room temperature curing rubber compounds that are used to encapsulate hard to coat items, and to form an insulating barrier between dissimilar metals.

Improved fastener materials i /olves the use of specially selected fasteners to prevent the bleeding rust, and frozen fasteners that would otherwise occur in the marine environment.

CORROSION CONTROL SYSTEMS

The corrosion control techniques that have been found most effective in preventing topside corrosion are listed in Table 3. Table 4 lists typical areas where these techniques are used. The following systems are the core of the topside corrosion control program for naval ships. The system numbering is that currently used in shipboard corrosion control handbooks produced by the Navy (4).

System One: Metal Spray Aluminum with high temperature, heat resistant sealer. Entire system applied in accordance with DOD-STD-2138.
0.010 to 0.015 inch of metal spray aluminum
0.003 inch of heat resisting sluminum paint (DOD-P-24555)
This system is designed for use where continuous or intermittent temperatures of over 175 degrees Fahrenheit are expected.

System Two: Metal Spray Aluminum with low temperature sealer. Entire system applied in accordance with DOD-STD-2138.
0.007 to 0.010 inch metal spray aluminum
0.004 to 0.008 inch epoxy paint (MIL-P-24441)
This system is used for normal ship topside conditions in areas where abrasion is frequent. The metal spray coating minimizes running rust and the need for maintenance to correct for rust staining.

System Three: Topcoats. This system covers a wide variety of different high performance paint systems. The major system emphasized is the use of epoxy-polyamide paint system MIL-P-24441, with and without the use of inorganic zinc coatings.
0.009 to 0.012 inch (3 coats) of MIL-P-24441 paint
0.003 inch of inorganic zinc paint
0.006 to 0.008 inch (2 coats) of MIL-P-24441 paint

These are the general high performance paint systems used on the topside of ships.

System Four: Powdered Coatings; Fluidized Bed and Electrostatically Applied. Powdered epoxy coatings are applied to parts that can be removed from the ship (electrical boxes, etc.) and which can be heated to temperatures of 450 degrees Fahrenheit. After surface preparation, the coating is applied to the surface

and heated to cure the coating. The coating forms a thick, durable, chemically resistant coating that can take substantial shipboard abuse without being seriously damaged.

System Five: Non-skid Deck Coatings. These coatings consist of a primer to prevent deck corrosion and coating that drys to a rough, sand-paper textured, surface that provides traction for foot and vehicle traffic on the deck. Rollable nonskid made to MIL-D-23003 is used for flight and hangar decks of aviation and air-capable ships. Sprayable nonskid made to MIL-D-24483 is used on the weather decks and other walking surfaces of surface ships.

System Six: Ceramic Coatings (MIL-C-81751). Ceramic coatings are used to provide corrosion protection to small steel items such as fasteners, fittings, etc. This is used on lieu of cadimium plating.

System Seven: Water Displacing Clear Corrosion Prreventive Compound (MIL-C-85054). This is a dry, clear, water displacing corrosion preventive compound that is applied to unpainted metal in enclosures for electrical and mechanical equipment. It is a short term (2 to 4 weeks) treatment for use with equipment where servicing is frequent.

System Eight: Antisieze Thread Compound (MIL-T-22361). This is a mixture of zinc dust and petrolatum that is used to prevent seizing during assembly or disassembly of components of equipment. The compound is used on threaded or unthreaded components that are engaged with other components made from similar or dissimilar metals.

System Nine: Improved Fastenters. These fasteners have been selected to prevent corrosion staining, and fastener seizing, caused by inappropriate use of fasteners. Table 5 details the fastener systems recommended.

System Ten: Sealing and Coating Compound (MIL-S-81733, Type I). This is a polysulfide compound that forms a room temperature curing rubber. The material is a two-component system that requires mixing prior to use. It is suitable for use by brushing or dipping and is used to cover bolt-heads, seams, and other areas to prevent contact with the with the environment.

System Eleven: Polysulfide Sealant (MIL-S-81733, Type IV). This material is used only as a sealing compund between the faying surfaces where metals are joined or fastened together. This is a two part system that will only cure in the absence of air. The cured material adheres well to aluminum, steel, and other metals.

System Twelve: Protection of Electrical Connectors. Heat shrinkable tubing (MIL-I-23053/15) provides an effective protection for connectors from the marine environment.

System Thirteen: Plastic Dielectric Barrier. This is particularly suitable for label plates. ABS (acrylonitrile

butadiene styrene) is cut 1/4 inch larger on all sides than the smaller of the two plates being joined. The label plate is mounted on the ABS plate and the assembly is attached using corrosion resistant fasteners.

System Fourteen: Vapor Phase Inhibitor (MIL-I-22110). This is a preservative for steel and aluminum parts which are enclosed in boxes or other areas. The inhibitor sublimes and is deposited on all exposed metal surfaces. The highly protective, invisible film formed provides corrosion resistance. In general, this system is best used where the box or enclosure is opened infrequently.

System Fifteen: Strippable Coating (MIL-S-8802). A polysulfide compound designed for use on items which have to be disassembled occasionally. The two components rubber cures at room temperature and has moderate adhesion to metals. The coating is protective but can be peeled from the protected substrate to allow access required for maintenance.

CONCLUSION

The net effect of using good corrosion engineering technologies has been a significant reduction in the shipboard maintenance manhour requirements. A demonstration program using the fifteen corrosion control systems described in the paper reduced topside maintenance requirements on the USS CUSHING (DD 985) by approximately 3000 man-days per year. The ship's commanding officer indicated that a potential savings of 5000 to 6000 man-days per year was possible if the procedures used in the demonstration were applied throughout the topside area. Expanding this savings to a six-hundred ship Navy through fleet-wide implementation of modern topside corrosion control techniques has the potential of reducing fleet maintenance requirements by 3,000,000 man-days per year (assuming a 600 ship navy and 5000 man-days per ship savings).

The above savings is going to be obtained by the application of corrosion fixes to existing ships that have built-in corrosion problems. Much greater savings could be obtained by designing and building ships with the intention of minimizing corrosion. The use of corrosion engineering design techniques, modern materials, and good fabrication techniques can prevent a great deal of the corrosion problems commonly encountered on naval ships.

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TABLE 1. Galvanic Series of Various Metals Exposed to Sea Water*

ACTIVE END	Magnesium
	Magnesium alloys
	Zinc
	Galvanized Steel
	Aluminum 1100
	Aluminum 6053
	Alclad
	Cadmium
	Aluminum 2024
	Mild Steel
	Cast Iron
	13% Chromium Stainless Steel
	Type 410 (Active)
	18-8 Stainless Steel
	Type 304 (Active)
	18-12-3 Stainless Steel
	Type 316 (Active)
	Lead-Tin Solders
	Manganese Bronze
	Naval Brass
	Nickel
	Admiralty Brass
	Copper
	Silicon Bronze
	70:30 Copper Nickel
	Nickel (Passive)
	67 Ni- 33 Cu Alloy (Monel)
	13% Chromium Stainless Steel
	Type 304 (Passive)
	18-12-3 Stainless Steel
	Type 316 (Passive)
	Silver
	Graphite
	Gold
PASSIVE END	Platinum

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*Adapted from reference (1)

TABLE 2. Factors influencing electrochemical corrosion of metals

> Temperature
> Heat Treatment
> Surface Condition
> Erosion
> Radiation
> Impurities
> Stress
> Pressure
> Oxygenation differences
> Concentration differences
> Biological growth

TABLE 3. Standard Corrosion control systems.

SYSTEM	DESCRIPTION
1	Metal spray aluminum with high temperature coating
2	Metal spray aluminum with low temperature coating
3	Inorganic zinc coatings with epoxy topcoats Epoxy anticorrosive paints and topcoats
4	Powdered coatings
5	Non-skid deck coating
6	Ceramic-metal coatings (MIL-C-81751)
7	Water displacing anticorrosion compound (MIL-C-85054)
8	Thread compound, antiseize (MIL-T-22361)
9	Improved fasteners
10	Polysulfide Sealing and Coating Compound MIL-S-81733)
11	Polysulfide Sealant on faying surfaces (MIL-S-81733, Type IV)
12	Protection of Electrical Connectors
13	Plastic Dielectric Barriers
14	Vapor phase inhibitor (UPI), (MIL-I-22110)
15	Strippable Coatings (MIL-S-8802)

TABLE 4. Common corrosion prone topside areas.

<u>PROBLEM AREAS</u>

Electrical Connection Boxes
Pipe Hangers
Telephone Box
Portable Lifeline Stanchion
Life Ring and Light Holder
Boat Davit Support Columns
Auxiliary Steam Valves
Steam Discharge
Bow Chock
Hawse Pipe and Cover
Jack Staff Hardware
Jack Staff Brace Stowage
Mooring Ring
Bitt
Access Hatch
Night UNREP Light Fixture
Capstan
Anchor Windlass
Chain Locker Cover and Securing Fittings
Brake Control Wheel
Deck Socket for Portable Davit
Fender Stowage
Tiedown
Wash Down Deck Components
Baxter Bolt
Life Boat Rack
Safety Net Fasteners (Swage Fittings)
Shore Steam Piping Riser and Valves
Antenna Fasteners
Water Tight Doors
Dry Chemical Fire Extinguisher, Stowage Bracket
Inclined Ladder
Vent Screens
Raised Deck Hatch
Deck Lights
Label Plates
Cable Stand-offs
Fire Lance
Roller Chocks
AFFF System Switches
Signal Searchlight
Fueling at Sea Fueling Receiver Assembly Support
Fueling at Sea Station Valves and Piping
Helo Line Up Lights
Fire Hose Spanner Wrench
Flush Deck Scuttle
Flush Deck Hatch

TABLE 5. Fastener Materials for Joining Metals (System 9).

METALS BEING JOINED	FASTENER MATERIAL TO USE (descending order of preference)	
	[3/8 inch Diameter	]3/8 inch Diameter
Steel with Steel	316 Stainless alloy	Steel with ceramic(1)
	304 Stainless alloy	316 Stainless alloy
	Other 18-8 Stainless	304 Stainless alloy
	Nickel-Copper (MONEL)	Other 18-8 Stainless
		Nickel-Copper (MONEL)
Steel with Aluminum Alloy (2)	316 Stainless alloy	316 Stainless alloy
	304 Stainless alloy	304 Stainless alloy
	Other 18-8 Stainelss	Other 18-8 Stainless
Aluminum Alloys with Aluminum	316 Stainless alloy	316 Stainless alloy
	304 Stainless alloy	304 Stainless alloy
	Other 18-8 Stainless	Other 18-8 Stainless
Nickel-Copper with Steel or with Nickel-Copper	Nickel-Copper	Nickel-Copper

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(1) Ceramic coating in accordance with MIL-C-81751
(2) Aluminum alloy fasteners are not approved
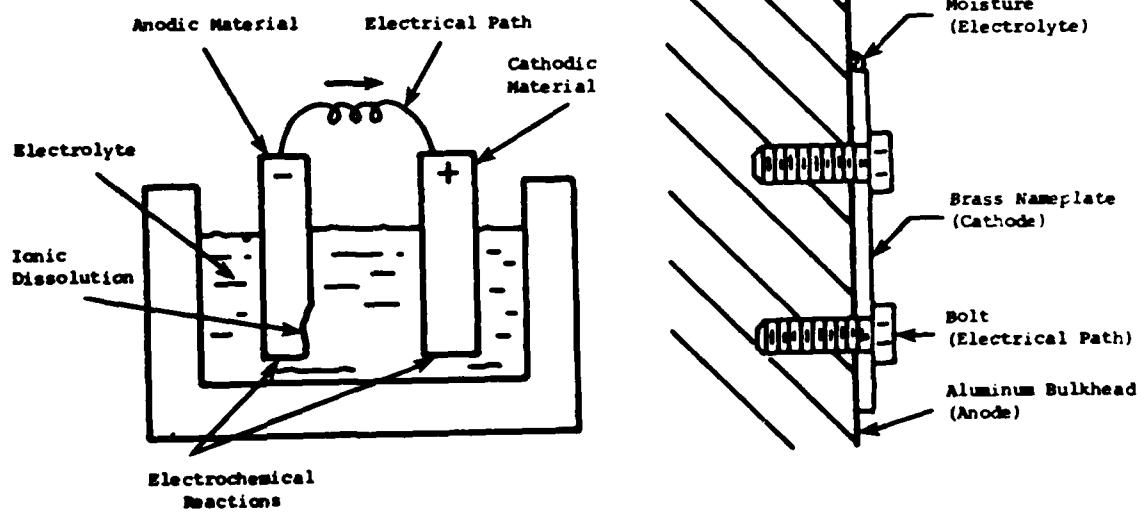
Figure 1. Typical electrochemical corrosion cells.